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HOLE QUALITY ASSURANCE BY OPTIMIZATION OF DRILLING PARAMETERS USING CUCKOO SEARCH ALGORITHM

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ABSTRACT

In order to obtain better hole quality (surface finish and hole diameter) in the least possible machining time, a befitting set of drilling parameters has to be identified. Therefore arises the necessity of a technique to devise the methodology for attaining the required set of parameters. Trial experiments were conducted on low carbon steel (SA515gr70) using an indexable drill as a tool. The mathematical modeling was based on experimental values obtained using full factorial DOE. The mathematical models of machining time, surface roughness, hole diameter were expressed a function of the input parameters cutting speed and feed. Cuckoo Search is carried out so as to retrieve the ideal set of drilling parameters to have a minimal machining time in order to get the desired surface finish and hole tolerance. Cuckoo search's ability to predict has been verified and the related results are presented.

KEYWORDS: Machining Time, Cuckoo Search Algorithm, Surface Roughness & DOE

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Original Article

INTRODUCTION

Bowing to the current industrial demands for high dimensional accuracy, surface finish at optimum production time and production cost in machining operations, our study focuses on improvising the machining parameters of hole making or drilling to get the desired demands. The operating parameters taken into consideration are the cutting speed and feed and they are subjected to constraints so as to obtain optimum production time at the sought dimensional accuracy and surface finish. We use Cuckoo Search Algorithm as the optimization technique in our study.

LITERATURE REVIEW

FarhadKolahan et al [1] has presented an approach on minimizing the total processing cost of drilling operations. The issues being taken into consideration were tool travel scheduling, tool switch scheduling, tool selection and machining speed specification and all of them have been addressed simultaneously. The total cost for processing includes that of tooling, machining, non-productive tool travelling and tool switching. Results obtained by the virtue of computational experiments reveal that the total processing cost can be reduced significantly over a reasonable search time.

Sivarao et al [2] has presented an experimental analysis on the rendition of carbide drill geometry in the hole making of GG25 gray cast iron. The process included identifying the parameters which enable surface roughness in drilling operation by integration of an expert system. Fuzzy expert system was used in the analysis of

the model that fit best in predicting the quality of deep drilled holes.

B. Y. Lee et al.[3] has presented an analysis with the use of an abductive network(AN) for modeling drilling processes. Once the process parameters (cutting speed, drill diameter and feed rate) are provided, the drilling performance (tool life, metal removal rate, thrust force and torque) can be figured by the abductive network. A simulated annealing optimization algorithm is then utilized on the developed network while searching for the optimal process parameters. Xin-She Yang et al [4] & [5] have developed a new optimization technique by the name of Cuckoo Search Algorithm and have made use of it in the comparative study of a set of test functions. The optimized parameters acquired by the cuckoo search algorithm are far better than those obtained by particle swarm optimization.

M. Pirtini et al [6] have presented a mathematical model based on the characteristics of the drilling process to arrive at better cutting forces and whole quality. The model simulates numerous cutting conditions in the progress of the experiment. The new model allows the visualization and determination of drilling whole parameters in 3D. Numerous experiments were completed to verify the model outputs and it was found to agree. Pinar Civicioglu et al [7] have made presented a conceptual comparison between Cuckoo Search (CS), Differential Evolution (DE), Artificial Bee Colony (ABC) and Particle Swarm Optimization (PSO). This was made possible by comparing them statistically through tests over 50 different benchmark functions. The outcomes reveal that the Cuckoo Search Algorithm has a very close problem success to that of the DE Algorithm and that these algorithms are robust and much more accurate than the Particle Swarm Optimization and Artificial Bee Colony algorithms.

E. Kuram et al [8] have presented a study where three different cutting fluids synthesized from sunflower oils and other two commercial types were used to find the surface roughness and the thrust force during drilling of AISI 304 austenitic steel with HSSE tool. The applied vegetable oils were subjected to a variety of constraints in the manner of changing spindle speeds and feed rates during drilling. The use of vegetable oils improved surface finish and aided in lowering the thrust force and relations between machining parameters (spindle speeds, feed rate, drilling depth) and thrust force, surface roughness were formulated.

Mohammed Elajrami et al. [9] have analyzed the effects of drilling parameters on the hole quality in an aluminum alloy 2024-T3. The hole quality was defined on the basis of roughness values and hole conicality. The results obtained indicated that the hole quality improved with high rotational speeds and low feed rates. Use of a new bit reduced the roughness by about 3 times and hole conicality by 2 times in comparison to an old bit. The variations and related changes by virtue of the other parameters were also analyzed.

EXPERIMENTAL METHODOLOGY

The experiments were performed on VSPQ 63 CNC drilling machine using Kennametal Indexable type drill tool of diameter 40 mm for drilling the carbon steel SA515gr70 work piece. The appropriate range for drilling parameters is taken from the specifications of the machine and the tool. DEA Scirocco CMM is used to measure the hole diameter of the drilled holes and Mitutoyo surface roughness tester is used for roughness measurements. The work of dimensions 500 mm x 500 mm x 50 mm has the following specifications and composition.

Figure 1: Drilling of work piece in CNC Drilling Machine

Figure 2: Work piece after completion of Drilling

Table 1: Specification and Composition of Work Material

Type	Low Carbon Steel
Standard name	SA515gr70
Grade	Pressure grade
Physical Properties	
Yield point	260 N/mm^2
Tensile strength	485 – 620 N/mm^2
Composition (in %)	
Carbon	0.31
Manganese	1.20
Silicon	0.15 – 0.4
Sulphur	0.035
Phosphorus	0.035

EXPERIMENTAL METHODOLOGY

A full factorial experiment was done with cutting speed and feed as the parameters. No. of Experiments: 25

Input Factors	Level				
	1	**2**	**3**	**4**	**5**
Cutting Speed (m/min)	80	90	100	110	120
Feed (mm/rev)	0.05	0.06	0.07	0.08	0.09

Response parameters: Machining time, Surface roughness and Hole diameter.

A CNC program is, written according to the speed and feed combination for each hole and dimensions of the work piece such that 5 rows and 5 columns of holes are obtained and for each row, speed is constant and for each column feed is constant. After drilling is complete, the work piece is cleaned again. Now surface roughness and hole diameter are measured using Surface roughness Tester and CMM respectively. The diameters (average) of the holes were calculated using (Arco CAD) of the CMM along the length of the holes. Six points were checked for determining the diameter in the horizontal plane, and the diameter was checked at height increments of 5 mm. The average value is taken. For each hole, the surface roughness is measured using the portable surface roughness tester. The results of the trial experiments are shown in Table 2.

Empirical Modeling and Analysis

The trial experiment has been conducted and the values have been tabulated. The values of machining time thus obtained are not optimized values. The objective now is to minimize the machining time for a particular value of surface roughness and hole diameter by varying the speed and feed parameters accordingly, thus making the objective function machining time a minimization problem. The values obtained from the pilot experiment were fed into the Design Expert

software version 8.0.7.1. RSM was used to obtain empirical relations for surface roughness, hole diameter and machining time, each with respect to speed and feed.

Response Surface Methodology

Response surface methodology (RSM) explores the relationships between several input variables and one or more response variables.

Table 2: Experimental Data

S. No	V,(m/min)	F,(m/rev)	MT, sec	SR, µm	D, mm
1	80	0.05	145	2.26	40.4766
2	80	0.06	131	2.39	40.3801
3	80	0.07	84	2.86	40.4156
4	80	0.08	86	2.94	40.6968
5	80	0.09	81	3.41	40.5784
6	90	0.05	98	2.24	40.5088
7	90	0.06	85	2.43	40.4567
8	90	0.07	83	2.63	40.3705
9	90	0.08	77	2.78	40.5770
10	90	0.09	67	3.21	40.4065
11	100	0.05	91	2.11	40.4543
12	100	0.06	81	2.24	40.4170
13	100	0.07	75	2.5	40.5620
14	100	0.08	63	2.73	40.6182
15	100	0.09	51	2.81	40.4267
16	110	0.05	82	1.8	40.1660
17	110	0.06	73	2.01	40.2122
18	110	0.07	64	2.22	40.2432
19	110	0.08	58	2.42	40.2512
20	110	0.09	48	2.59	40.2764
21	120	0.05	85	1.34	40.0345
22	120	0.06	67	1.42	40.0476
23	120	0.07	60	1.67	40.0519
24	120	0.08	50	1.89	40.1336
25	120	0.09	47	2.24	40.2170

The equations obtained from the software are:

$MT= 716.17429 – (8.21386* V) – (4244* F) + (14.7* V * F) + 0.030714*V^2) + (12428.57* F^2)$

$SR=-2.96686+ (0.10652* V) + (16.98* F) – (0.146* V * F) – (6.1E-4 * V^2) + (144.28571* F^2)$

$D=+38.08548 + (0.055417* V) + (0.25784* F) + (0.020554* V * F) – (3.37240E-4*V^2) + (1.94571*F^2)$

Where, V= Speed; F= feed; MT = Machining time, SR = surface finish and D = hole diameter

ANOVA and Response Plots

Table 3: Analysis of Variance (ANOVA) for Machining Time

Source	Sum of Squares	Df	Mean Square	F value	P-value
V	5428.82	1	5428.82	89.86	<0.0001
F	5345.78	1	5345.78	88.49	<0.0001
VF	216.09	1	216.09	3.58	0.0739
V^2	660.36	1	660.36	10.93	0.0037
F^2	108.13	1	108.13	1.79	0.1967

Table 3: Contd.,					
Residual	1147.86	19	60.41		
Total	**12907.04**	**24**			

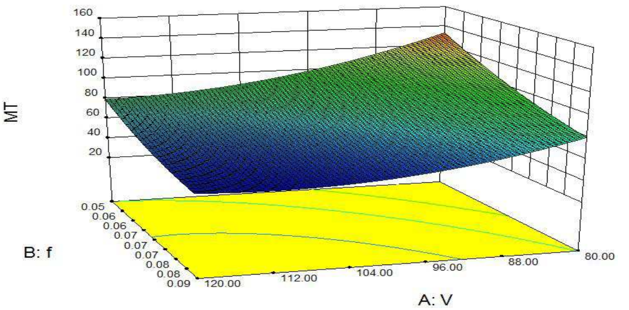

Figure 3: Combined Effect of Speed and Feed on Machining Time

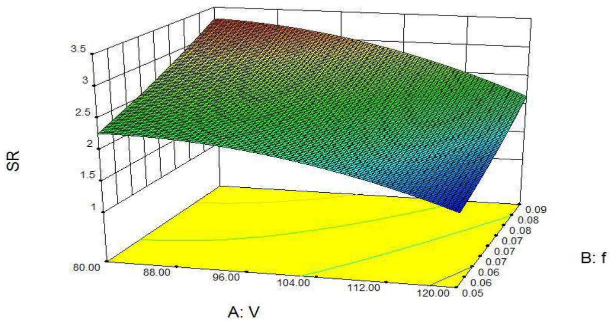

Figure 4: Combined Effect of Speed and Feed on Surface Roughness

Table 4: Analysis of Variance (ANOVA) for Surface Roughness

Source	Sum of Squares	Df	Mean Square	F value	P-value
V	3.30	1	3.30	499.87	<0.0001
F	2.55	1	2.55	385.87	<0.0001
VF	0.021	1	0.021	3.23	0.0884
V^2	0.26	1	0.26	39.43	<0.0001
F^2	0.015	1	0.015	2.21	0.1539
Residual	0.13	19	6.607E-003		
Total	**6.27**	**24**			

Table 5: Analysis of Variance (ANOVA) for Hole Diameter

Source	Sum of Squares	Df	Mean Square	F value	P-value
V	0.56	1	1	62.42	<0.0001
F	0.033	1	0.033	3.72	<0.0001
VF	4.225E-4	1	4.225E-4	0.047	0.8307
V^2	0.080	1	0.080	8.86	0.0078
F^2	2.650E-6	1	2.650E-6	2.949E-4	0.9865
Residual	0.17	19	8.988E-3		
Total	**0.85**	**24**			

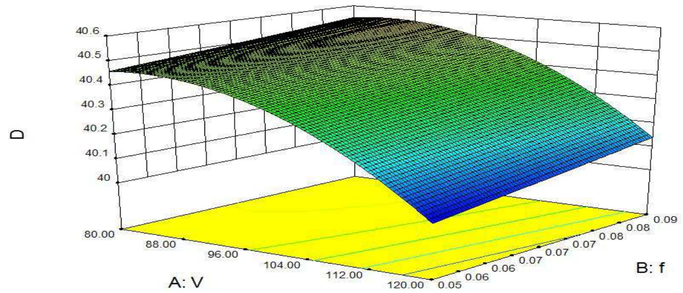

Figure 5: Combined Effect of Speed and Feed on Hole Diameter

Optimization Problem

Three cases of optimization problem are taken to validate the proposed method of optimization of drilling parameters. They are as follows:

CASE 1: WIDER TOLERANCE Min MT subjected to SR $\leq$ 3.2 and D $\leq$ 40.25

CASE 2: NOMINAL TOLERANCE Min MT subjected to SR $\leq$ 2.4 and D $\leq$ 40.16

CASE 3: STRICT TOLERANCE Min MT subjected to SR $\leq$ 1.6 and D $\leq$ 40.05

Where, MT = machining time, SR = surface roughness and D = hole diameter.

The cases are based on ISO standard for tolerances. Consider that the required 40 mm hole should satisfy strict tolerances, then it should satisfy case 3, for nominal tolerances case 2 will satisfy the requirements and if tolerance is not of much importance then satisfaction of case 1 is enough.

Cuckoo Search Algorithm

The algorithm is basically based on the egg-laying regime of a cuckoo as it tends to lay its eggs in the nests of other birds. The existing solutions (old eggs) are replaced by the new solution (new egg) and the nest with the highest quality of eggs gets carried over to the further generation. The probability that the host bird discovering the alien egg is $p_a \in [0,1]$ and if it discovers it either gets the egg off the nest or it deserts the nest.

Pseudo code for Cuckoo Search

Objective function

Generate initial population of host nests

While (stop criterion)

Get a cuckoo randomly by Levy flights

Evaluate its quality/fitness F_i

Choose a nest among n (say j) randomly

If $F_i > F_j$

end

Abandon a fraction (p_a) of worse nests [and build new ones at new locations via Levy flights]

Keep the best solutions (or nests with quality solutions)

Rank the solutions and find the current best

End while

Post process results and visualization

This pseudo code has been adapted from the book entitled *Nature inspired meta-heuristic algorithms* [10].

Parameters for Cuckoo Search Algorithm

Number of iterations performed : 100

No. of nests : 100

p_a (Probability of the discovery of an alien egg in its nest by a host bird): 0.25

Obj. Function : Minimize Machining time

Constraints : Surface Finish, hole Diameter

Software used : MATLAB

MATLAB Simulation

Using Cuckoo search algorithm, a MATLAB program code was developed to optimize machining time. Speed and feed were provided as inputs to the program, with machining time being the objective function. Surface roughness and hole diameter were made as the constraint function and the best values of speed and feed were obtained for the minimum machining time. The equation obtained using the Design Expert software was used in the program to calculate the same. The program was made to run for 100 nests and 100 iterations to obtain the most optimal solution. Each nest consists of speed and feed as the input parameters and the machining time as the output parameter for a constrained value of surface roughness and hole diameter.

For the 1st iteration, a set of 100 nests for speed and feed are initialized such that when these values are substituted in the surface roughness and the hole diameter equation, the desired speed and feed value is obtained. Subsequently, the machining time is determined. From the 100 nests of machining time determined, the least value is chosen as the best nest for the 1st iteration. The corresponding input parameters of the best machining time are then chosen to calculate the speed and feed for the next iteration, as per the formula of the cuckoo search algorithm. Post the 1st iteration, subsequent iterations are carried out such that machining time is continually optimized. The runtime of the program was found to be 19 seconds.

Results of Optimization

The program was successfully executed in MATLAB and the results so obtained are studied. The values fall within the constrained limits. The following table shows the best values of speed and feed for minimum machining time for case 1, 2 and 3.

Table 6: Predicted Values of Machining Time using Cuckoo Search Algorithm

Case	V (m/min)	F (mm/rev)	MT (sec)	SR (µm)	D (mm)
1	115.0068 (915)	0.09	48.63	2.402	40.249
2	119.154 (948)	0.09	49.88	2.196	40.137
3	120 (954)	0.06008	64.4	1.512	40.049

Validation of Optimal Drilling Parameters

The optimized results, obtained from the MATLAB program for Cuckoo search Algorithm were validated in CNC VSPQ 63 drilling machineto test the robustness of the proposed CS optimization technique and its effectiveness in the manufacturing industry. The same experimental setup which was used for the trial experiment, consisting of the SA515gr70 work piece, Kennametal indexable drill (40 mm), surface Roughness Tester and CMM were used for the confirmatory experiments. The speed and feed values obtained from the MATLAB program were set in the CNC program control panel. For each trial, corresponding machining time, surface roughness and hole diameter values were measured as shown in Table 7.

Table 7: Validation Experimental Values

Case	V (m/min)	F (mm/rev)	MT (sec)	SR (µm)	D (mm)
1	115.0068 (915)	0.09	54	2.612	40.256
2	119.154 (948)	0.09	57	2.342	40.148
3	120 (954)	0.06008	69	1.58	40.056

RESULTS AND DISCUSSIONS

The following tables indicate the accuracy of CS in determining the optimized drilling parameters for the necessary properties subjected to constraints. The results of the experiments elucidate the importance and necessity of CS.

$$\text{Error (\%)} = \frac{\Pr edicted - observed}{Observed} x100$$

Accuracy (%) = 100 – (% of Error)

Table 8: Predicted Vs. Observed Machining Time

Case	V (m/min) (RPM)	F (mm/rev)	MT (sec)		Error %	Accuracy %
			Predicted	Observed		
1	115.0068(915)	0.09	48.63	54	9.9	90.1
2	119.154 (948)	0.09	49.88	57	12.49	87.51
3	120 (954)	0.06008	64.4	69	6.67	93.33

Avg. error = 9.68%; Avg. accuracy = 90.32%

Table 9: Predicted Vs. Observed Surface Roughness

Case	V (m/min) (RPM)	F (mm/rev)	SR(µm)		Error %	Accuracy %
			Predicted	Observed		
1	115.0068(915)	0.09	2.402	2.612	8.04	91.96
2	119.154 (948)	0.09	2.196	2.342	6.23	93.77
3	120 (954)	0.06008	1.512	1.58	4.3	95.7

Avg. error = 6.19%; Avg. accuracy = 93.81%

Table 10: Predicted Vs. Observed Hole Diameter

Case	V (m/min) (RPM)	F (mm/rev)	Hole DiaD, mm		Error %	Accuracy %
			Predicted	Observed		
1	115.0068(915)	0.09	40.249	40.256	0.017	99.983
2	119.154 (948)	0.09	40.137	40.148	0.027	99.973
3	120 (954)	0.06008	40.049	40.056	0.017	99.983

Avg. error = 0.02%; Avg. accuracy = 99.979%

The average error of predicted values to the values for machining time, surface roughness and hole diameter is found to be 9.68%, 6.19% and 0.02% with average accuracy levels of 90.32%, 93.81% and 99.979% respectively. The accuracy level is more than 90% for all the three responses, which shows the effectiveness of Cuckoo Search Algorithm in predicting optimal machining parameters. The slightest deviation in values can be attributed to the vibrations and the properties of the work and tool.

CONCLUSIONS

The following points were observed from the present work:

- CS has a high grade of accuracy which reasons out its high viability.
- The technique put forward is efficient both time-wise and cost-wise and eliminates the risks and errors to be accommodated in case of live experimenting.
- The method of selection of cutting parameters explained here is simpler and does not require any prior experience on the part of the process planner.
- Feed rate improvises machining time to a better extent comparable to speed.
- High surface finish and less deviation in hole diameter are found at high cutting speed and low feed.
- The error percentage of the proposed process is found to be 9.68% for machining time, 6.19% for surface roughness and 0.02% for hole diameter.
- The accuracy percentage of the proposed process is found to be 90.32% for machining time, 93.81% for surface roughness and 99.979% for hole diameter.
- The result of validation experiments confirms the accuracy of CS in the prediction of optimal parameters.

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